Computer Networks

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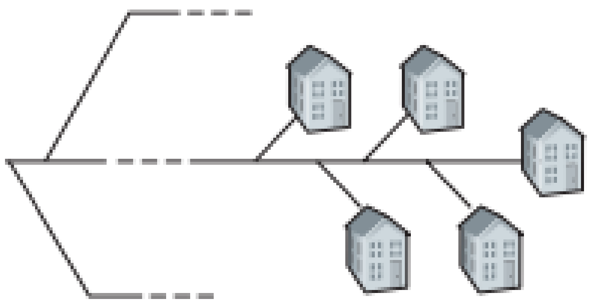
Link Access

Link Types

- There are two types of network links
- **A point-to-point link** consists of a single sender at one end of the link and a single receiver at the other end of the link. Many link-layer protocols have been designed for point-to-point links such as the point-to-point protocol (PPP).
  - Circuit-switched networks require dedicated point-to-point connections
- **A broadcast link**, can have multiple sending and receiving nodes all connected to the same, single, shared broadcast channel.
  - packet-switched network

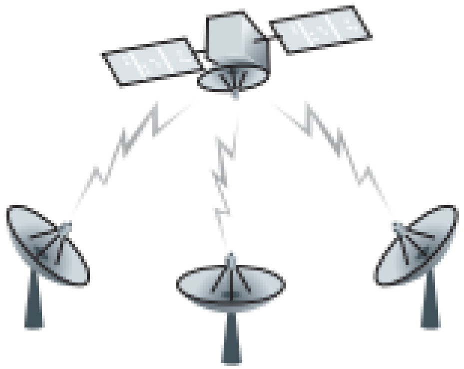
Shared Medium

Shared wire

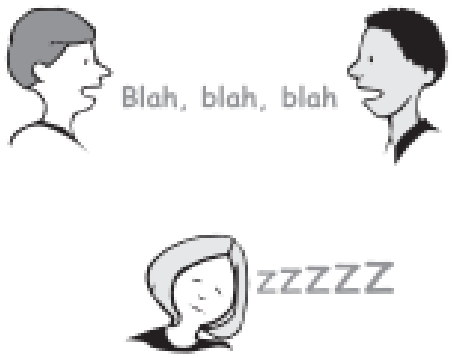


Shared wireless
(for example, WiFi)

Satellite



party



Multiple Access Problem

- Traditional one-way broadcast (that is, one fixed node transmitting to many receiving nodes e.g. Television) don’t have the multiple access problem.
- However, nodes on a computer network broadcast channel can both send and receive.
- It is necessary to share the broadcast medium (wire / frequency / air) efficiently and effectively in a fair manner among the various nodes
- Protocols that enable multiple users to share a finite amount of frequency and time resources are Media Access Control (MAC) Protocol.

Human Analogy for Medium Access

- Party or Classroom, where one person talk and other listen, similarly share the same, single, broadcast medium.
- A central problem here is to determine who gets to talk and when?
- As humans, we've evolved many set of protocols for sharing the broadcast channel
  - "Give everyone a chance to speak."
  - "Don't speak until you are spoken to."
  - "Raise your hand if you have a question."
  - "Don't interrupt when someone is speaking."
  - "Don't fall asleep when someone is talking to you."

MAC Categories

- MAC Protocols can be broadly classified into the following categories
  1. Channel Partitioning Protocols or Contention-free Protocols
  2. Random Access Protocols or Contention-based Protocols
  3. Taking-turns Protocols

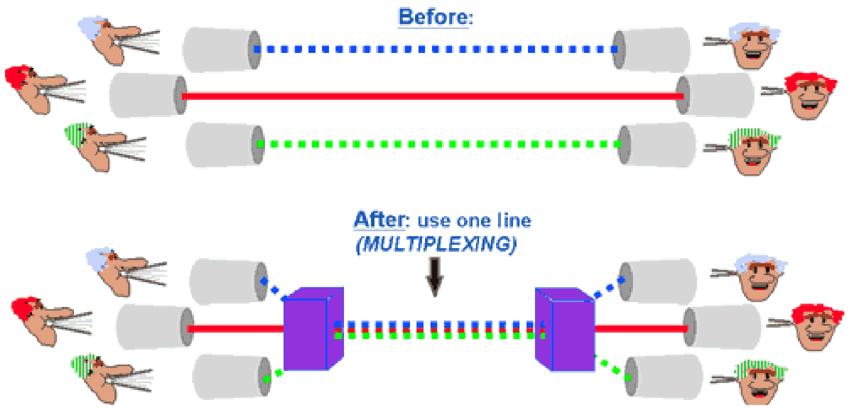
Key Concepts

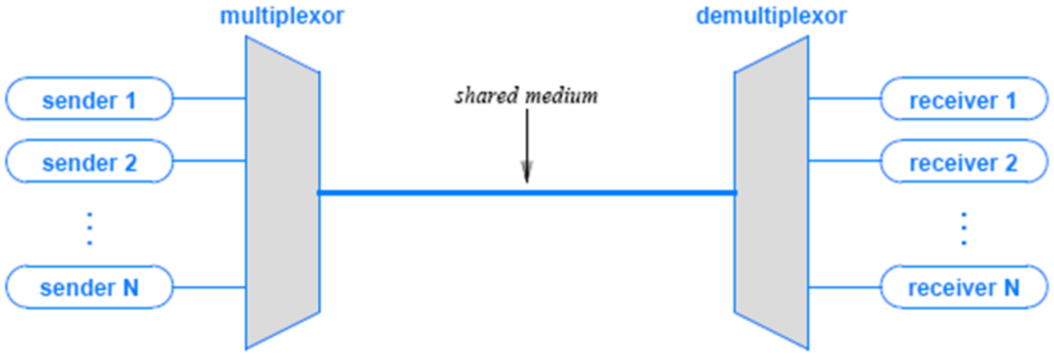
- **Collisions**
  - When two or more transmissions are received at the same time, it is said that there is a collision at the receiver (the two transmissions ought to be with the same frequency and at the same time.).
    - Show Me
- **Capture**
  - If the strength of one of the signals is sufficiently large than the others, this signal could potentially be captured at the receiver. The other signal is called “INTERFERENCE”.
- **Attenuation / Path Loss:** (Signal Strength is proportional 1/d)
- **Shadowing:** Due to hills or other large objects

Channel Partitioning Protocols
Or
Contention-free Protocols

The Concept of Multiplexing

- Multiplexing refer to the combination of information streams from multiple sources for transmission over a shared medium
- Demultiplexing refer to the separation of a combination back into separate information streams
- Multiplexor combines information from the senders for transmission in such a way that the demultiplexor can separate the information for receivers



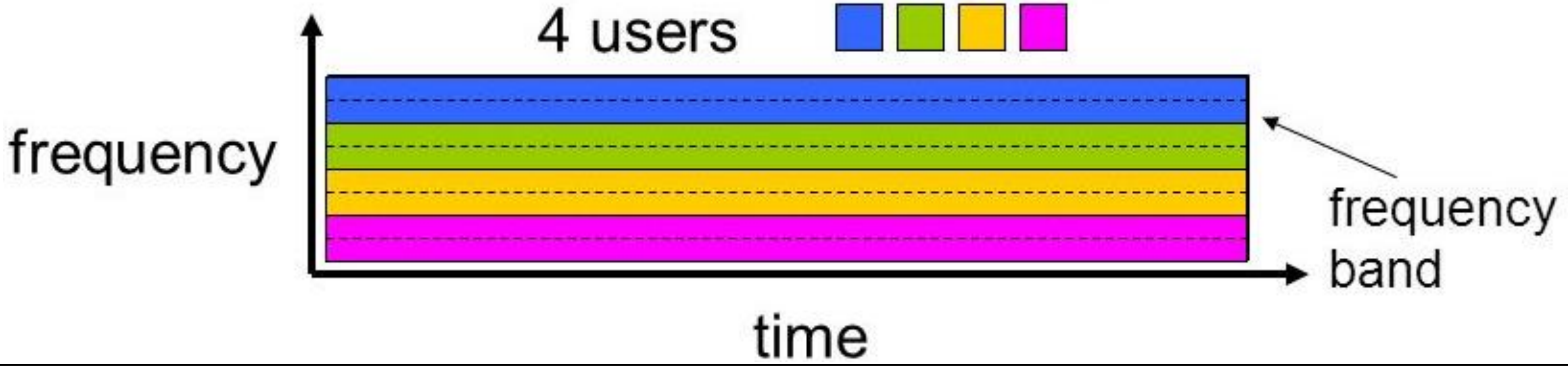


The Basic Types of Multiplexing

- Basic approaches to multiplexing
  - Frequency Division Multiplexing (FDM)
  - Time Division Multiplexing (TDM)
  - Code Division Multiplexing (CDM)

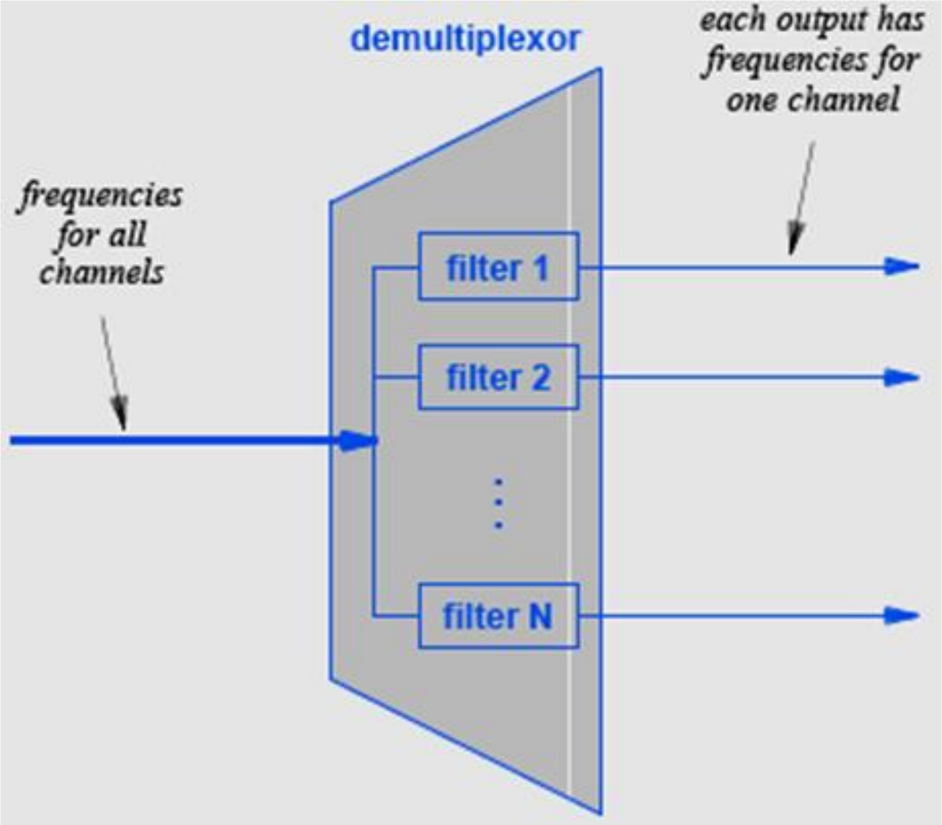
Frequency Division Multiplexing

- A group of senders can transmit signals simultaneously
  - By using separate channel (i.e., carrier frequency)
- The total bandwidth available in a communication medium is divided into a series of **non-overlapping frequency bands**, each of which is used to carry a separate signal. This allows a single transmission medium such as a cable or optical fiber to be shared by multiple independent signals.
  - For example a **cable television or DSL modems** transmit large amounts of data through twisted pair telephone lines, among many other uses.



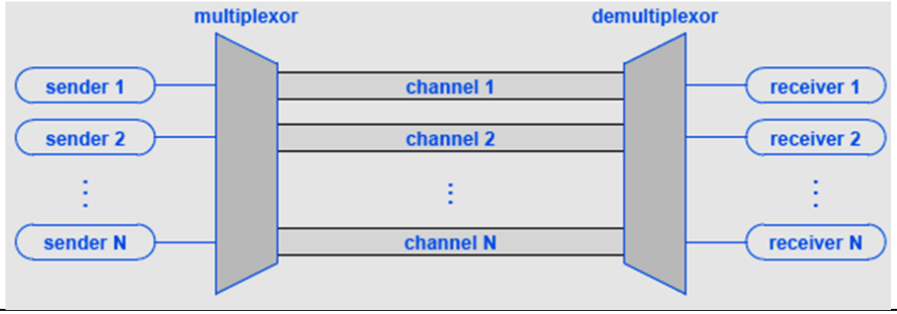
Frequency Division Multiplexing

- A demultiplexer applies a set of filters that each extract the required range of frequencies for each receiver.



Frequency Division Multiplexing

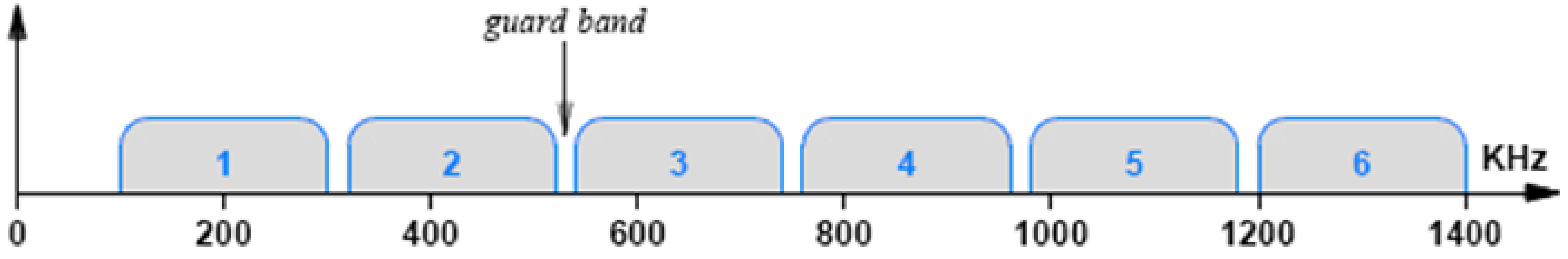
- FDM allows **simultaneous use** of a transmission medium by each user
- FDM **provides each pair with a private/ separate transmission path**
- Practical FDM systems - there are some limitations
  - If the frequencies of two channels overlaps or are too close, interference can occur, hence a gap between channels known as a guard band, is required
  - **Complex hardware** for multiplexing and demultiplexing
  - The overall frequency hence **bandwidth is divided** by the total number of users



FDM Example

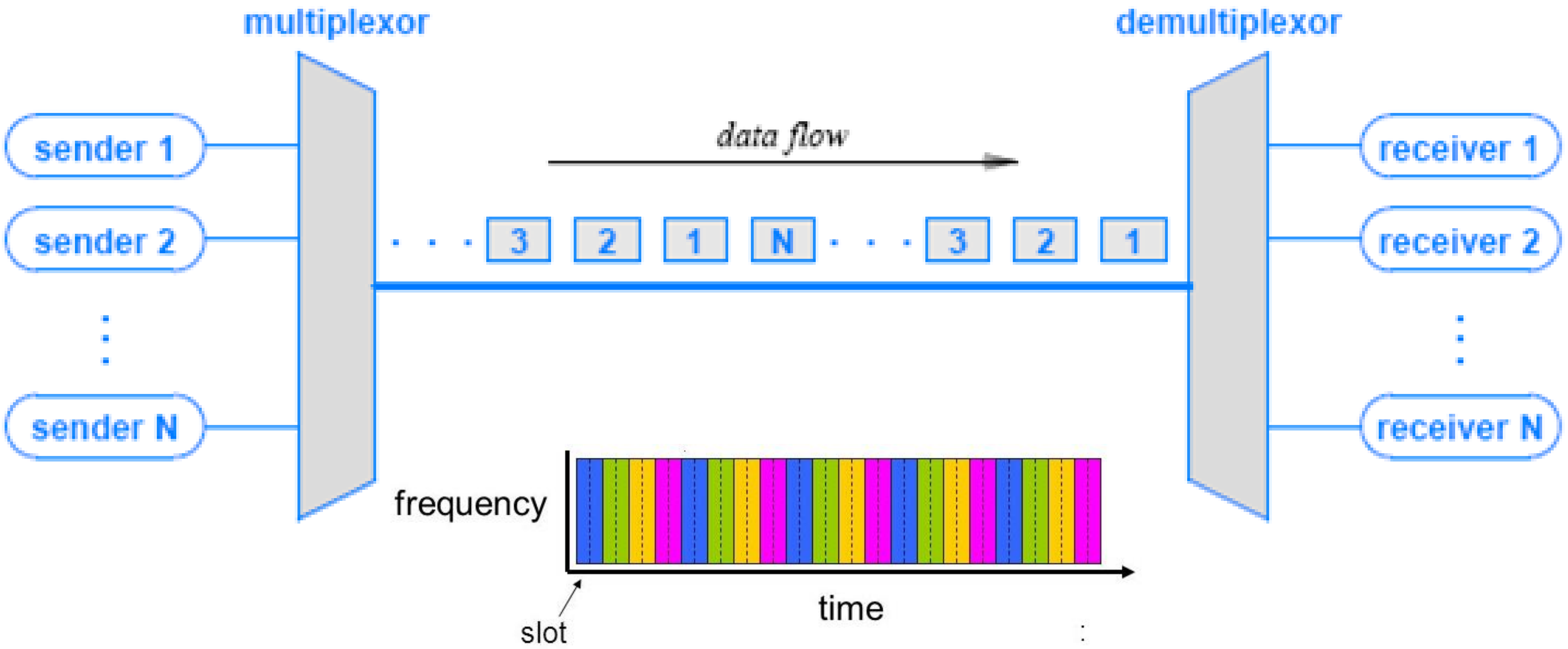
- 200 KHz to each of 6 channels with a guard band of 20 KHz between each

Channel	Frequencies Used
1	100 KHz - 300 KHz
2	320 KHz - 520 KHz
3	540 KHz - 740 KHz
4	760 KHz - 960 KHz
5	980 KHz - 1180 KHz
6	1200 KHz - 1400 KHz



Time Division Multiplexing (TDM)

- TDM assigns time slots to each channel repeatedly
  - multiplexing in time simply means transmitting an item from one source, then transmitting an item from another source, and so on

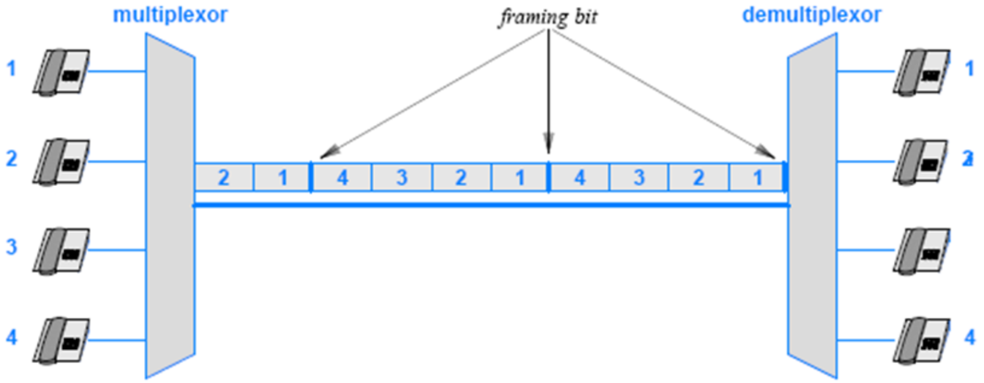


Synchronous TDM

- The multiplexor accepts input from attached devices in a round-robin fashion
- Figure illustrates how synchronous TDM works for a system of five senders

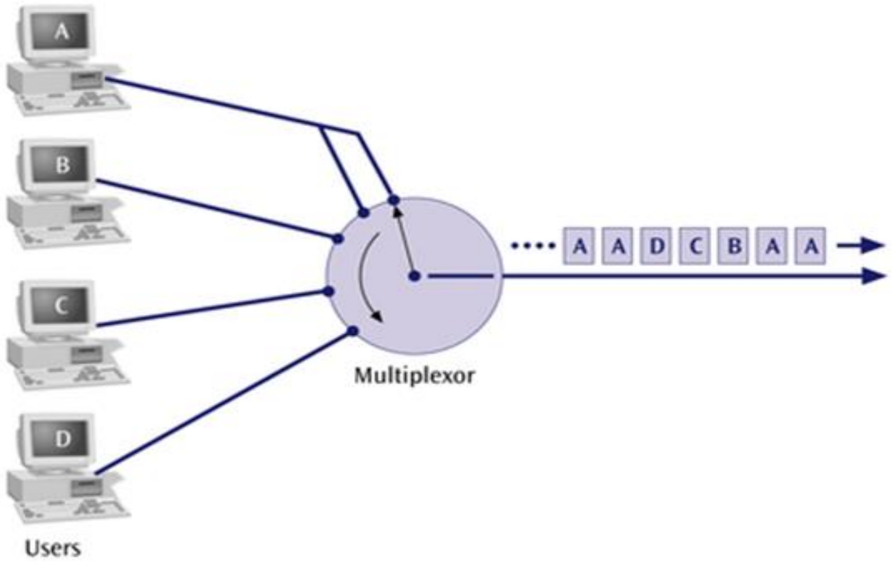
Framing in Synchronous TDM

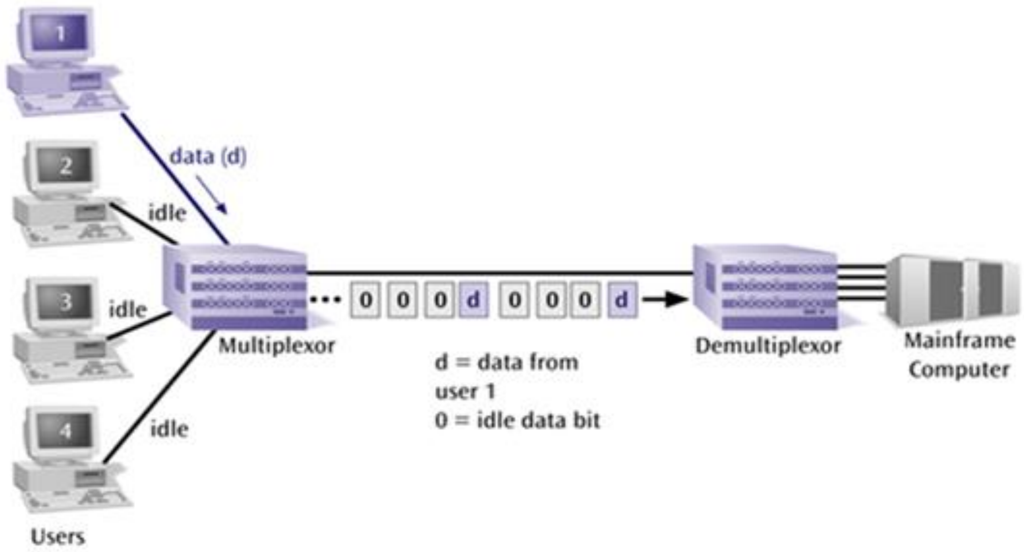
- Why is synchronization needed?
  - A synchronous TDM sends one slot after another, but does not indicate when a slot begins and when a slot ends
  - So a the demultiplexer cannot tell where a slot begins– a slight difference in the clocks can cause a demultiplexer to misinterpret the bit stream
- To prevent misinterpretation, an extra frame byte is used at the end of each round
- The demultiplexor synchronize with multiplexer using the framing byte



The Problem with Synchronous TDM

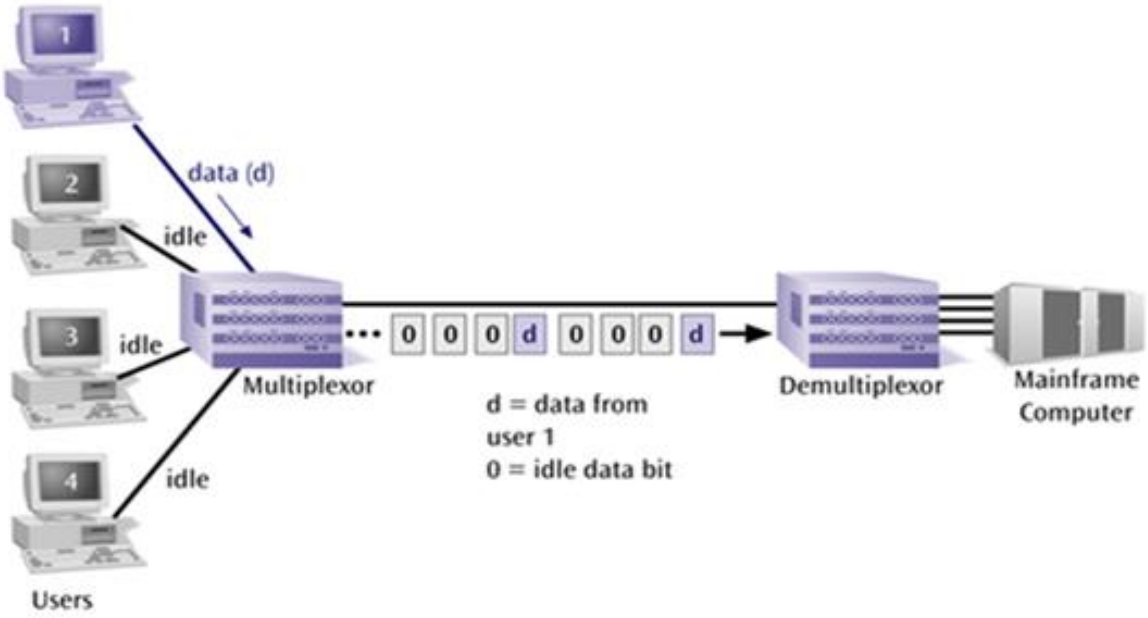
- If one device generates data at a faster rate than other devices, then the multiplexor must either give that device more time or buffer its excessive data.
- Similarly, If a device has nothing to transmit, the multiplexor must still insert a piece of data from that device into the multiplexed stream.





The Problem with Synchronous TDM

- Synchronous TDM works well if each source produces data at a uniform, fixed rate
- Many sources generate data at random
    - if the corresponding source has not produced data by the time the slot must be sent, the synchronous multiplexor leaves a slot unfilled, by assigning it a zero value

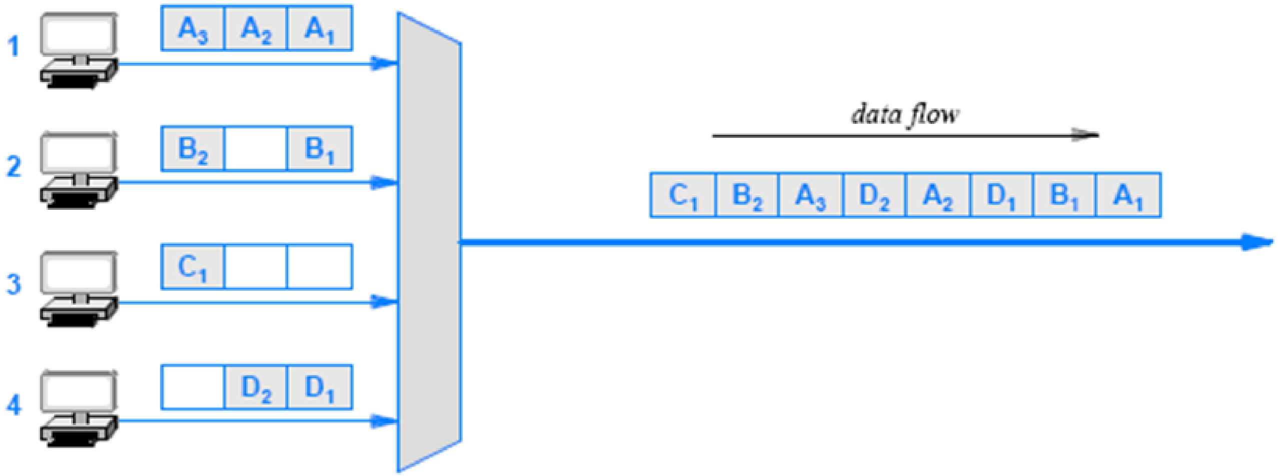


Statistical TDM

- One technique to increase the overall data rate and channel utilization is known as **statistical TDM or asynchronous TDM**
- The technique is straightforward:
  - select items for transmission in a round-robin fashion
  - but instead of leaving a slot unfilled, skip any source that does not have data ready
- By eliminating unused slots
  - statistical TDM takes less time to send the same amount of data
- A statistical multiplexor does not require a high speed line since STDM does not assume all sources will transmit all of the time!

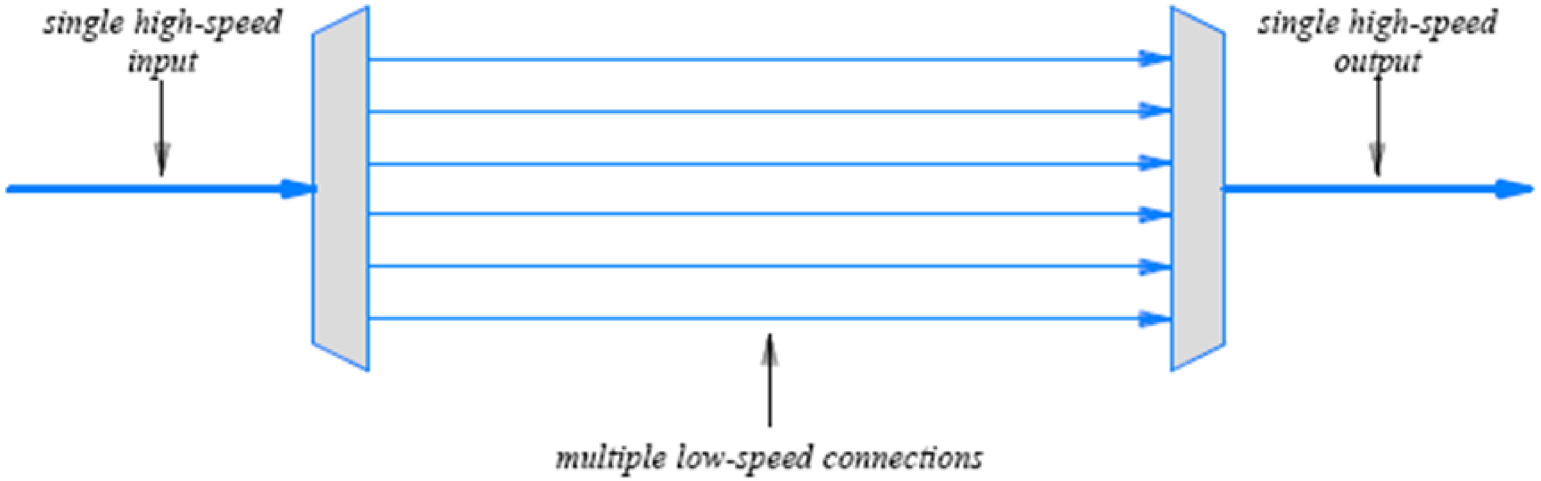
Statistical TDM

- Statistical multiplexing incurs extra overhead
  - In a synchronous TDM system a demultiplexor knows that every N slot corresponds to a given receiver
  - In a statistical multiplexing system, the data in a given slot can correspond to any receiver
- Each slot must contain the identification of the receiver to which the data is being sent



Inverse Multiplexing

- Assume a case where a connection between two points consists of multiple transmission media
  - but no single medium has a bit rate that is sufficient
- To solve the problem, multiplexing is used in reverse
  - split a high-speed digital input over multiple lower-speed outputs for transmission and combine the results at the receiving end



Code Division Multiplexing (CDM)

- CDM used in cellular networks and for some satellite communication
- CDM does not rely on physical properties
  - such as frequency or time
- CDM relies on an interesting mathematical idea
- Each sender is assigned a unique binary code Ci
  - that is known as a chip sequence
- At any point in time, each sender has data Di to transmit
  - The senders multiply Ci x Di and transmit the results
- The senders transmit at the same time
  - and the data are added together
- To extract data Di, a receiver multiplies the sum by Ci

Code Division Multiplexing (CDM)

- Consider we have four stations 1, 2, 3 and 4 (with data d_1, d_2 and so on).
- The chip code assigned to first station is C_1, to the second is C_2 and so on.
- The codes C_1, $C_{2,}$ C_3 and C_4 assigned to each station should have two properties:
  - If we multiply each code by another, we get 0.
  - If we multiply each code by itself, we get 4. (No. of stations).
- Each station multiplies its data by its code i.e. $d_1 . C_1$ and so on
- The sum of all stations ($d_1 . C_1 + d_2 . C_2 + d_3 . C_3 + d_4 . C_4$) is transmitted.
- To get the data sent by station 1, the receiver multiply the signals with the code of station 1 and then divide the result by the number of users
- d1. C1 . **C1**+ d2 . C2. **C1**+ d3 . **C3**. C1 + d4 . **C4**. C1= **4 x d1**

CDM Example

Sender	Chip Sequence	Data Value
A	1 0	1 0 1 0
B	1 1	0 1 1 0

- The first step consists of converting the binary values into vectors that use -1 to represent 0:

$C_1 = (1, -1)$ $V_1 = (1, -1, 1, -1)$ $C_2 = (1, 1)$ $V_2 = (-1, 1, 1, -1)$

Multiplying $C_1 \times V_1$ and $C_2 \times V_2$ produces:

$((1, -1), (-1, 1), (1, -1), (-1, 1))$ $((-1, -1), (1, 1), (1, 1), (-1, -1))$

- If we think of the resulting values as a sequence of signal strengths to be transmitted at the same time
  - the resulting signal will be the sum of the two signals

$$
\begin{array}{rrrrrrrrr}
 & 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\
+ & -1 & -1 & 1 & 1 & 1 & 1 & -1 & -1 \\
\hline
 & 0 & -2 & 0 & 2 & 2 & 0 & -2 & 0
\end{array}
$$

Code Division Multiplexing

- Thus, a receiver if want to compute the message of Sender A, computes:

$$(1,\ -1)\ \bullet\ ((0,\ -2),\ (0,\ 2),\ (2,\ 0),\ (-2,\ 0))$$

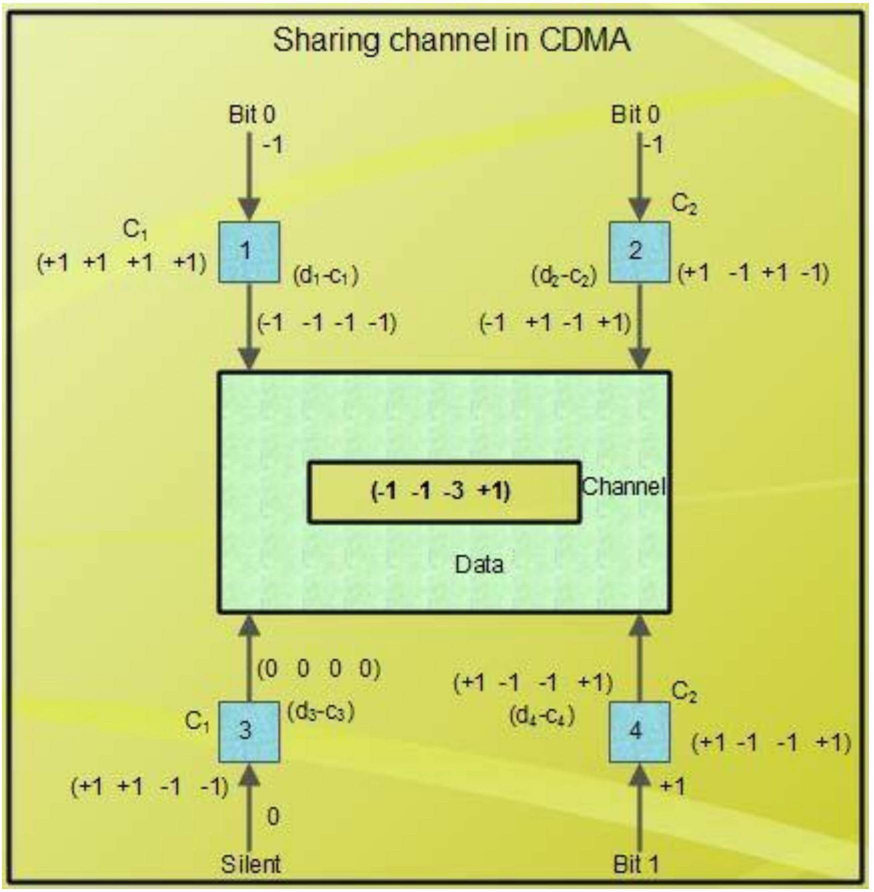
to get:

$$((0+2),\ (0-2),\ (2+0),\ (-2+0))$$

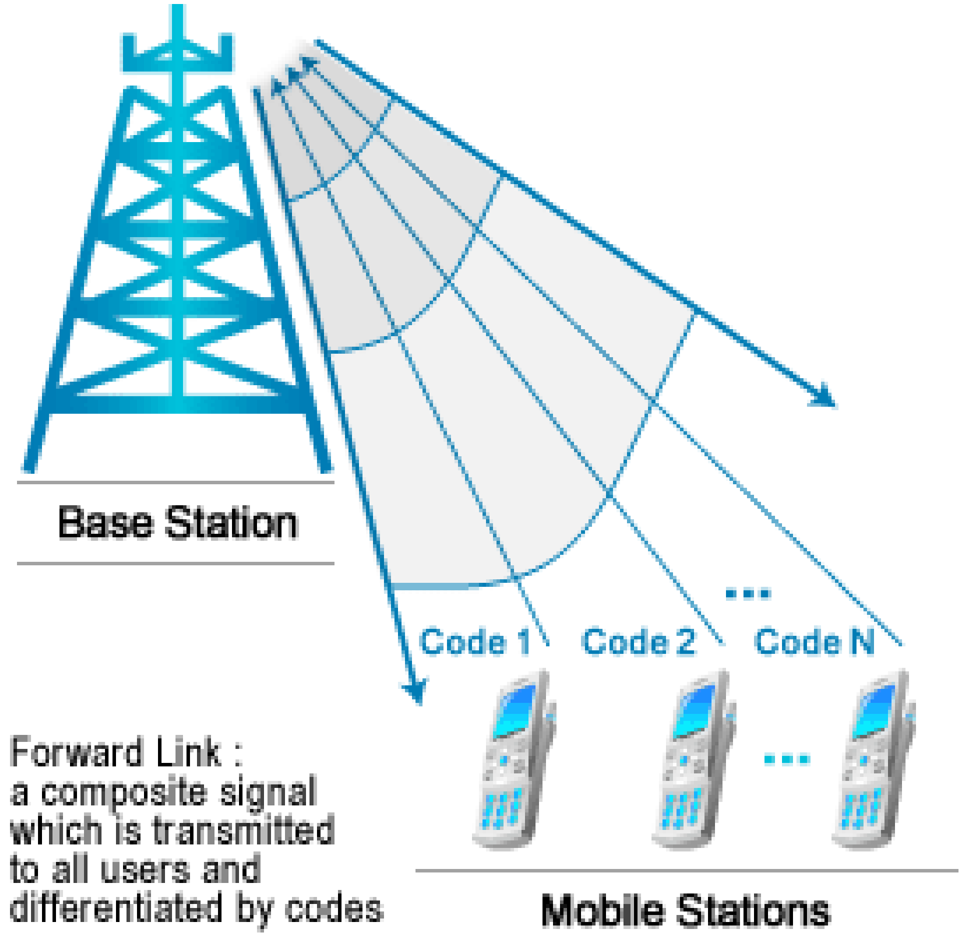
- Now treats the result as a sequence, and converts the result to binary by interpreting positive values as binary 1 and negative values as 0
  - Interpreting the result as a sequence produces: (2 -2 2 -2)
  - Dividing by the total number of users produce: (1 -1 1 -1)
  - Which becomes the binary value: (1 0 1 0)
  - Note that 1010 is the correct value of Sender A
  - Receiver 2 can extract the data of Sender B from the same transmission

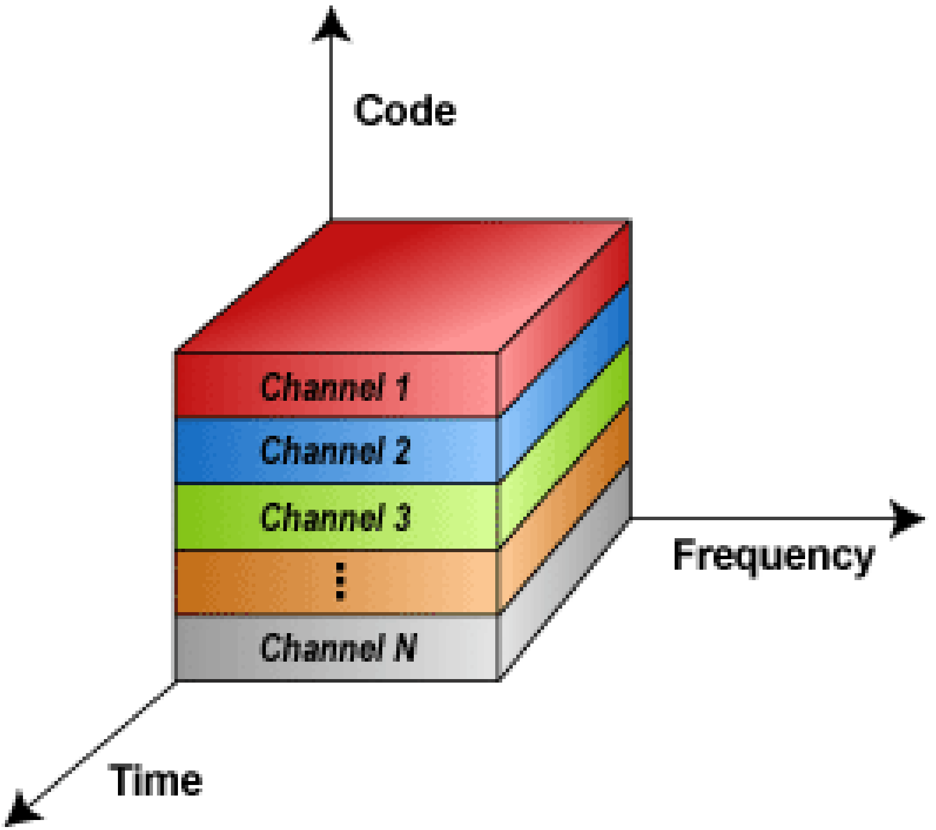
CDM Example 2

- Finding the data sent by Station 2.
  - Multiply the total data on the channel by the code [+ 1 -1 +1 -1], of station 2
  - [-1 -1 -3+1] . [+1 -1 +1 -1]= [-1+1-3-1] = -4
  - Divide by total users = -4/4 = -1
  - -1 --> bit 0



CDM





CDMA in which each channel is assigned a unique code which is orthogonal to codes used by other users.